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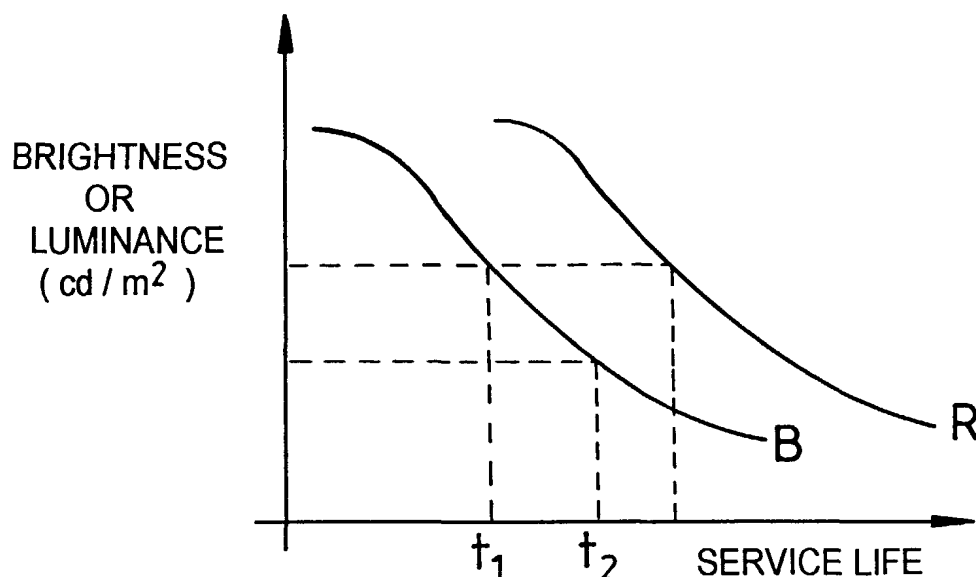
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(54) Title: LIGHT-EMITTING DEVICES



(57) Abstract: A light-emitting device comprising: a first electroluminescent element for emitting light of a first colour when energised; and a second electroluminescent element for emitting light of a second colour when energised, the first electroluminescent element having an active lifetime which is greater than that of the second electroluminescent element; characterised in that the second element is configured to operate at a lower brightness than the first element.



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TITLE: LIGHT-EMITTING DEVICES

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DESCRIPTION

15       The present invention relates to a light-emitting device, particularly an electroluminescent device and displays incorporating such devices. The electroluminescence for the electroluminescent device may be provided by means of an organic light-emissive material  
20 (see for example International Publication WO90/13148 which describes electroluminescent semi-conductive conjugated polymers, such as PPV).

By way of background, Figure 1 shows the typical cross-sectional structure of an organic light-emissive  
25 device. The device is fabricated on a substrate (1) coated with a transparent first electrode (2) such as indium-tin-oxide. The coated substrate is overcoated with at least one layer of a thin film of an electroluminescent organic

material (3) and a final layer forming a second electrode (4) which is typically of metal. By using a transparent substrate (e.g. of glass or plastics material), light generated in the film (3) is able to leave the device by passing through the first electrode (2).

The performance of electroluminescent devices has advanced rapidly over the past few years. Due to their high efficiencies, the devices show potential for a wide range of display applications, from simple backlights to graphic displays, such as television screens, computer monitors and palm-top devices which may consist of several million pixels. However, there is considerable variation in the active lifetimes of red, green and blue organic electroluminescent systems, including polymer systems. For the purposes of the present specification, the active lifetime of an electroluminescent element is defined as the maximum time for which the element is able to produce at least a display-monitor level of brightness (for example, set at  $100\text{cd/m}^2$ ) when operating under a given drive scheme. For example, an electroluminescent device with a red light emitting polymer may have an active life of 30,000 hours at 5 volts, whereas a device with a blue light-emitting polymer may have an active life of only 1500 hours at the same voltage (see table 1).

The disparity in active lifetimes of organic light-emissive materials is significant because one factor in determining the useful life or service life of a graphic display incorporating such materials is governed by the

shortest of the active lifetimes of the different polymers employed. (Another factor concerns decay rates causing colour shift, which can reduce overall colour purity, i.e. 'white' becomes 'off-white', and possibly also produce non-uniformity in the display). Accordingly, attempts have been made to improve the service life of graphic displays. For example, research has been conducted into upgrading the active lifetime of the 'weak link' in such displays; namely, the relatively short-lived blue light-emitting polymers. Also, systems have been devised to compensate the device driving current - either by using a sensing mechanism or by predicting the rate of performance decay in complex drive compensation electronics - to maintain optimal performance with time. However, compensation mechanisms require complex and expensive circuitry which may also impose restrictions on the available aperture ratio.

An object of the present invention is to improve the service life of graphic displays incorporating organic light-emissive materials.

In accordance with a first aspect of the present invention, there is provided a light-emitting device comprising: a first electroluminescent element for emitting light of a first colour when energised; and a second electroluminescent element for emitting light of a second colour when energised, the first electroluminescent element having an active lifetime which is greater than that of the second electroluminescent element, characterised in that

the second element is configured to operate at a lower brightness than the first element.

The brightness or luminescence of light emitted by an object may be measured in candela per square meter, and is  
5 a measure of the amount of light (number of photons) emitted per second per unit solid angle per unit area, as corrected for the sensitivity of the eye. The instantaneous brightness may vary - intentionally or otherwise - from one moment to another. When considering  
10 light-emitting devices for use in graphic displays, variations in instantaneous brightness may occur too rapidly to be detected by the human eye. Accordingly, the "brightness" which is of interest to the present invention is time-averaged to the extent necessary to smooth out  
15 localised or high speed variations in instantaneous brightness.

The first and second electroluminescent elements may comprise organic light emissive materials, and may be polymeric materials such as those discussed in WO90/13148  
20 or WO92/03490.

The present applicant has appreciated the implication of the correlation between brightness and service life of devices employing organic light-emissive materials. The correlation is illustrated schematically in Figure 2 for  
25 two electroluminescent elements employing different organic light-emissive materials, for example a red light emitter (R) and a blue light emitter (B) which have different active lifetimes. The correlation for each may be

summarised as a relatively high brightness being indicative of a relatively short service life and vice versa. If both organic light-emissive materials are operated continuously at the same level of brightness, the material with the shortest active lifetime will fail (i.e. reach the end of its active life) first (in the example, the blue will fail before the red) and the device will be judged to have failed prematurely at  $t_1$ . However if the material with the shortest active lifetime is operated continuously at a lower level of brightness than the other material, the service life of the device will be extended to  $t_2$ .

The ratio between the brightness ( $B_1$ ) of the first electroluminescent element and the brightness ( $B_2$ ) of the second electroluminescent element may be substantially equal to the ratio between the active lifetime ( $\tau_1$ ) of the first element and the active lifetime ( $\tau_2$ ) of the second element (i.e.  $B_1/B_2 = \tau_1/\tau_2$ ). Suppose, for example, that there is an order of magnitude difference in the active lifetime of the two elements (e.g. active lifetime of the first element is 30,000 hrs and the active lifetime of the second element is 3,000 hrs). If the two elements are to fail at substantially the same time, it may be necessary to operate the second element at one tenth of the brightness of the first element.

There may be another advantage to operating the second element (shorter active lifetime) at a lower brightness than the first element. When operated continuously, the

amount of light emitted per unit time by the first and second elements may decrease or decay with time, with the rate of decay perhaps being greater for the second element.

Thus, the perceived colour of the light-emitting device with both elements energised will drift with time because the contribution by the second element to the overall light output slowly decreases. However, by operating the second element at a lower brightness than the second element may have the effect of retarding the rate of decay in the amount of light emitted per unit time. In other words, the rates of decay in the amount of light emitted per unit time by the first and second elements may become more even. Hence, the problem of perceived colour drift with time may be alleviated.

The first and second electroluminescent elements may be energised by a common potential difference, for example by using a common cathode. The correlation between brightness (or luminance in  $\text{cd/m}^2$ ) and voltage is illustrated schematically in Figure 3 for two electroluminescent elements employing different materials, for example a red light emitter (RED) and a blue light emitter (BLUE) which have different driving voltage characteristics. In fact, the red light emitter (RED) has a lower driving voltage characteristic than the blue light emitter (BLUE). Thus, by driving the two elements at a common potential ( $V_1$ ), the red light emitter will be operating at a higher brightness than the blue light emitter ( $B_1 > B_2$ ). Accordingly, the goal of extending the



service life of the device is attainable by operating at a common potential.

In an alternative embodiment, the first and second elements may be energised by different potentials. The second element may be energised at a higher potential than the first element. Referring to Figure 3, driving the blue light emitter (BLUE) at  $V_2$  will yield a brightness  $B_3$  which is greater than  $B_2$ . Of course, if performance characteristics were reversed in Figure 3 or the RED and BLUE curves cross over in the drive potential regime, the first element may be energised at a higher potential than the second element.

The second element may be energised in pulses. Pulsing has the effect of lowering the time-averaged brightness as compared to operating continuously, e.g. at a constant potential. Thus, even though the blue light emitter (BLUE) is operating at a higher potential than before ( $V_2 > V_1$ ), the service life of the device may still be greater than  $t_1$  because the emitter is only energised for a fraction (e.g. less than  $1/10$ ) of the overall time. The second element may be pulsed at a frequency in excess of 50 Hz, and perhaps at 100 Hz. Although lower frequencies would also have the effect of lowering the time-averaged brightness, it may be desirable in some applications to pulse at a rate which is faster than the eye response function. Each pulse may last for perhaps 200 microseconds, with perhaps 20 milliseconds between pulses.

The first and second elements may be pulsed, with the

time-averaged brightness for the first element being greater than that for the second element. Thus, if the first and second elements are operating at a common potential, the first element may be energised for longer 5 periods than the second element. This may be achieved by pulsing the first element more frequently than the second element or by increasing the duration of each pulse (pulse width) for the first element relative to that for the second element. Pulsing of both elements may be useful for 10 light-emitting devices incorporated in passive matrix-driven displays.

The second element may be adapted to emit light over a larger area than the first element. The difference in light-emitting areas may be such that the total light 15 output from the first element is substantially equal to that from the second element over a comparable time frame. For example, if there is no difference in duration of activation, the ratio between the light-emitting area ( $A_1$ ) of the first element and the light-emitting area ( $A_2$ ) of the 20 second element may be substantially equal to the ratio between the brightness ( $B_2$ ) of the second element and the brightness ( $B_1$ ) of the first element (i.e.  $A_1/A_2 \approx B_2/B_1$ ). By operating the second element at a lower time-averaged brightness than the first element, the amount of light 25 observed by an observer from the elements will differ if the elements are of equal size (assuming the duration of activation is equal). This is because with normal eye

constraints (e.g. sampling and resolution factors) the amount of light received from an element is related to the product of the time-averaged brightness and the area over which light is emitted. However, by increasing the size of  
5 the second element relative to the first element, such a difference may be offset somewhat or even totally compensated.

The brightnesses of the first and second electroluminescent elements may be chosen such that the  
10 half-lives of the first and second electroluminescent elements are substantially equal.

The choice of driving conditions for the two electroluminescent elements may be governed by material properties. Figure 4 shows a plot of efficiency against  
15 current density for red and blue light-emissive polymers in the first and second electroluminescent elements, respectively. If the device is to operate at optimum efficiency, the first electroluminescent element will need to operate at a first current density  $\sigma_1$ , whilst the second  
20 electroluminescent element will need to operate at a second current density  $\sigma_2$ , with  $\sigma_1 > \sigma_2$ . The current density  $\sigma_2$  may, for example, be achieved by operating the second element at a higher potential than the first element, and achieve a lower brightness by pulsing the second element.

25 The device may further comprise a third electroluminescent element for emitting light of a third colour when energised, the third electroluminescent element

having an active lifetime in between that of the first and second electroluminescent elements. All elements may comprise organic light-emissive materials, and may be polymeric materials such as those disclosed in WO90/13148 5 or WO92/03490. All elements may be energised by a common potential difference, or at different potentials, perhaps with the second element at the highest potential and the first element at the lowest, and perhaps with the second element being pulsed.

10     The third element may be adapted to emit light over an area which is greater than the first element but smaller than the second element. The reason for doing this is again to achieve the desired total light output per unit time. The effect of doing this is the same as increasing 15 the service life of the second element at the expense of the first element. This is because in practice, when dealing with a finite substrate, the light-emitting area of the third element will be normalised and the areas of the first and second elements will be relatively smaller and 20 larger respectively.

There is also provided a graphic display incorporating a light-emitting device according to the first aspect of the invention, wherein each electroluminescent element in the device corresponds to a pixel for displaying graphic 25 information.

In accordance with a second aspect of the present invention, there is provided a light-emitting device comprising: a first electroluminescent element for emitting

light of a first brightness ( $B_1$ ) when energised by a predetermined potential; and a second electroluminescent element for emitting light of a second brightness ( $B_2$ ) when energised by the predetermined potential, the second brightness being less than the first brightness; characterised by means for energising the first and second electroluminescent elements at the predetermined potential, and in that the second electroluminescent element has a larger light-emitting area than the first electroluminescent element.

The second aspect of the present invention provides for increasing the light-emitting area of the element with the lowest brightness relative to that of the element with the highest brightness, with a view to reducing the difference in the total light emitted by the elements in unit time. In the absence of such an areal compensation, the brightest element (i.e. the first electroluminescent element) will emit more light than the other element when operating at a common potential.

The first or second electroluminescent element may comprise an organic light-emissive material. The organic light-emissive material may be polymeric.

The energising means may comprise at least one electrode common to both electroluminescent elements. For example, the energising means may comprise an anode and a cathode, each common to both electroluminescent elements.

The total light emitted by the first electroluminescent element may be substantially equal to

the total light emitted by the second electroluminescent element in any given time interval when both electroluminescent elements are energised. The ratio of the first brightness ( $B_1$ ) to the second brightness ( $B_2$ ) may be substantially equal to the ratio of the light-emitting area of the second electroluminescent element ( $A_2$ ) to the light-emitting area of the first electroluminescent element ( $A_1$ ), i.e.  $B_1/B_2 \approx A_2/A_1$ .

The first and second electroluminescent elements may emit light of first and second colours respectively when energised, the first and second colours being selected from the group consisting of red, green and blue.

The light-emitting device may further comprise: a third electroluminescent element for emitting light of a third brightness when energised by the predetermined potential, the third brightness being in between that of the first and second brightness; and means for energising the third electroluminescent element at the predetermined potential. The third electroluminescent element may have a light-emitting area greater than that of the first element and less than that of the second element.

There may be provided a graphic display comprising a light-emitting device according to the second aspect of the invention, wherein each electroluminescent element corresponds to a pixel for displaying graphic information.

In accordance with a third aspect of the invention, there is provided a light-emitting device comprising: a

first electroluminescent element for emitting light of a first colour when energized; and a second electroluminescent element for emitting light of a second colour when energized, the first electroluminescent element emitting light at a lower luminance than that of the second electroluminescent element when each is energized with optimal efficiency; characterized in that the first and second electroluminescent elements are configured to operate at the same perceived brightness when both electroluminescent elements are energized with optimal efficiency.

The third aspect of the invention provides for operating light emitting elements - having different luminance versus efficiency characteristics - at optimal efficiency whilst at the same time achieving uniformity in the light output from each element. Such a light emitting device may be valuable where lifetime is not an issue, which may well be the case in certain "throwaway" applications.

The first or second electroluminescent elements may comprise an organic light-emissive material. The organic light-emissive material may be polymeric. The first and second electroluminescent elements may be energized by a common potential.

The first and second electroluminescent elements may be energized by different potentials, and the second electroluminescent element may be energized at a higher potential than the first electroluminescent element. The

energizing potential applied to one or both of the electroluminescent elements may be pulsed, with the first electroluminescent element perhaps being energized for longer periods than the second electroluminescent element.

5 For example, the first electroluminescent element may be pulsed more frequently or with a greater pulse width than the second electroluminescent element.

The first electroluminescent element may be configured to emit light over a larger area than the second  
10 electroluminescent element. The ratio between the light emitting areas of the first and second electroluminescent elements ( $A_1$  and  $A_2$ ) may be substantially equal to the ratio between the luminances of the second and first electroluminescent elements ( $L_2$  and  $L_1$ ) respectively when  
15 energized at optimal efficiency, i.e.,  $A_1/A_2 = L_2/L_1$ .

The first and second colours of light emitted from the electroluminescent elements are selected from the group consisting of red, green and blue. The device may further comprise a third electroluminescent element for emitting  
20 light of a third colour when energized, the third electroluminescent element emitting light at a luminance in between that of the first and second electroluminescent elements when energized with optimal efficiency.

There may also be provided a graphic display  
25 comprising a light-emitting device according to the third aspect of the invention, wherein each electroluminescent element corresponds to a pixel for displaying graphic information.



In accordance with a fourth aspect of the invention, there is provided a light-emitting device comprising: a first electroluminescent element for emitting light of a first colour when energized; and a second  
5 electroluminescent element for emitting light of a second colour when energized, the first electroluminescent element having a half-life which is greater than that of the second electroluminescent element when each is energized with optimal efficiency; characterized in that the second  
10 electroluminescent element is configured to operate at a lower brightness than the first electroluminescent element when both are energized with optimal efficiency.

The third aspect of the invention provides for operating light-emitting elements - having different half-  
15 life versus efficiency characteristics - at optimal efficiency and in such a way that the service life of the device is increased.

The first or second electroluminescent elements may comprise an organic light-emissive material. The organic  
20 light-emissive material may be polymeric. The first and second electroluminescent elements may be energized by a common potential.

The first and second electroluminescent elements may be energized by different potentials, and the second  
25 electroluminescent element may be energized at a higher potential than the first electroluminescent element. The energizing potential applied to one or both of the electroluminescent elements may be pulsed with the first

electroluminescent element perhaps being energized for longer periods than the second electroluminescent element. For example, the second electroluminescent element may only be energized for short periods whilst the first  
5 electroluminescent element is operated continuously. The ratio between the energization times for the first and second electroluminescent elements ( $t_1$  and  $t_2$ ) may be substantially equal to the ratio between the half-lives of the second and first electroluminescent elements ( $T_2$  and  $T_1$ )  
10 respectively when energized at optimal efficiency, i.e.  
$$t_1/t_2 \approx T_2/T_1.$$

The first electroluminescent element may be configured to emit light over a larger area than the second electroluminescent element. The ratio between the light  
15 emitting areas of the first and second electroluminescent elements ( $A_1$  and  $A_2$ ) may be substantially equal to the ratio between the brightnesses of the second and first electroluminescent elements ( $B_2$  and  $B_1$ ) respectively when energized at optimal efficiency, i.e.,  $A_1/A_2 \approx B_2/B_1$ .

20 The first and second colours of light emitted from the electroluminescent elements are selected from the group consisting of red, green and blue. The device may further comprise a third electroluminescent element for emitting light of a third colour when energized, the third  
25 electroluminescent element emitting light at a luminance in between that of the first and second electroluminescent elements when energized with optimal efficiency.

There may also be provided a graphic display comprising a light-emitting device according to the third aspect of the invention, wherein each electroluminescent element corresponds to a pixel for displaying graphic information.

An embodiment of the invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 is a schematic illustration of an organic light-emissive device known in the art;

Figure 2 is a schematic illustration showing how brightness affects the service life of the device of Figure 1 operating under constant drive conditions;

Figure 3 is a schematic plot of brightness against voltage for two different electroluminescent elements;

Figure 4 is a schematic plot of efficiency against current density for the first and second elements;

Figure 5 is a graph showing pixel half-life as a function of pixel luminance for the colours red, green and blue;

Figure 6 is a graph showing luminance versus voltage curves for red, green and blue light emitting polymer pixels;

Figure 7 is a graph showing efficiency versus luminance for the colours red, green and blue;

Figure 8 is a graph showing half-life versus pixel voltage for the colours red, green and blue.

Figure 9 is a graph showing half-life versus

efficiency for the colours red, green and blue.

Figure 10 is a schematic illustration of a graphic display embodying the present invention;

Figure 11 shows pulse driving for "red" and "green" 5 elements in figure 10;

Figure 12 shows schematically how different pixel areas can be achieved; and

Figure 13 shows a possible driving scheme providing different energy pulse widths to each pixel colour in 10 figure 12.

The perceived brightness of a display depends on the following parameters:

$$Luminance_{perceived} = Luminance_{pixel} \cdot Area\_ratio_{pixel} \cdot Pulse\_width\_ratio$$

In this equation the  $Luminance_{perceived}$  is the luminance seen 15 by the eye assuming that the pixel size is below the eye resolution limit and the pulse repetition rate is faster than the eye response. The luminance of a pixel depends on:

$$Luminance_{pixel} = f[(Efficiency_{pixel} (time\_total, V_{pixel} \text{ or } I_{pixel}))]$$

20 Accordingly, the perceived luminance depends on:

1. Pixel area ratios
2. Pixel pulse width ratio
3. Pixel efficiency
4. Pixel half-life, or how the efficiency is 25 changing with time
5. The current or voltage supplied to the pixel, i.e. drive conditions.

Of these five parameters, the efficiency and half-life

are defined by the device/material properties and cannot be altered. The other parameters however can be altered. The pixel area ratio can be modified for a display, but cannot be changed during operation. For a certain device construction a common cathode and anode could be chosen, this will lead to an identical voltage across pixels with different colours. The pulse width ratio can be changed during operation by the driver circuit. In Table 2, an overview is given how the perceived luminance, display life time, display efficiency and common voltage can be optimised towards area ratio and pulse width.

In theory, therefore, there are five different optimised operational regimes which may be summarised as:

- 1.1 Equal (perceived) luminance, different voltage, different efficiency, equal half-life;
- 1.2 Equal (perceived) luminance, equal voltage, different efficiency, different half-life;
- 1.3 Equal (perceived) luminance, different voltage, optimal efficiency, different half-life;
- 1.4 Different (perceived) luminance, equal voltage, different efficiency, equal half-life; and
- 1.5 Different (perceived) luminance, different voltage, optimal efficiency, equal half-life.

1.1 Equal luminance, different voltage, different efficiency, equal half-life

For an ideal three-colour display all the display area can be used for the pixels. In a standard display, all the pixels have the same area and therefore 1/3 of the display

area is available for each colour. If a display should have a luminance for each colour of e.g.,  $100 \text{ cd/m}^2$ , a pixel luminance of  $300 \text{ cd/m}^2$  per pixel is required. In the example of Figure 5, the display lifetime is controlled by the lowest half-life and is in this example 333 hrs. The overall display lifetime can be increased, say to 800 hrs, by optimising the pixels' areas. [In the example of Figure 5, it is assumed that the initial luminance multiplied with the half-life is constant]. However, the optimisation can also be done for other relationships. In order for the perceived luminance to be  $100 \text{ cd/m}^2 / (\text{pixel area ratio})$ . From Figure 5, the luminance values needed for the blue green and red pixels are 125, 625 and  $2500 \text{ cd/m}^2$  in order to obtain identical half-lives. Therefore the relative pixel area ratios are  $A(\text{blue}) : A(\text{green}) : A(\text{red}) = 100/125 : 100/625 : 100/2500$  i.e.,  $0.8 : 0.16 : 0.04$  instead of  $1/3 : 1/3 : 1/3$ .

#### 1.2. Equal luminance, equal voltage, different efficiency, different half-life.

In some display applications, a common pixel voltage might be needed for instance in the case of a common anode and cathode e.g., to produce a cheap white backlight. Suppose, for example, luminance voltage curves are as shown in Figure 6. By driving all the pixels at an identical voltage of 4V, each different coloured pixel will have a different luminance. In order to obtain uniform perceived luminance three options are available:

##### 1. Optimise relative pixel areas.

The relative pixel areas can now be optimised for the perceived brightness to be identical for each colour.

$$Lum_{perceived} = Lum_{pixel} \cdot Relative\_pixel\_area$$

For a uniform perceived luminance the relative pixels areas should be  $A(\text{blue}):A(\text{green}):A(\text{red}) = 1/85 : 1/200 : 1/3666 = 0.691 : 0.293 : 0.016$  (since sum of area ratios must equal unity) resulting in a  $58.7 \text{ cd/m}^2$  perceived luminance for each colour. The disadvantage of this solution is, that for each required display luminance another pixel area ratio is required. The next solution overcomes this problem.

## 2. Optimise pixel driving time.

The luminance of a pixel can also be controlled by adjusting the driving pulse width of a pixel. The ratio of the pulse width for the blue, green and red pixel are identical to point 1. This solution has the advantage, that the pulse width can be adjusted if another display luminance is required.

## 3. Optimise both driving time and pixel area.

Both solutions mentioned above can be combined. Choose an appropriate pixel area ratio resulting in very similar pulse width. This avoids the need of high frequency pulses, which can result in worse performance and higher driver IC design and fabrication costs.

## 1.3. Equal luminance, different voltage, optimal efficiency, different half-life.

The display can also be optimised towards equal

luminance and optimal efficiency per colour. In this example, the power losses due to pulsed driving are neglected. As can be seen from Figure 7 each colour has an optimal efficiency at a different luminance. The perceived  
5 luminance may be made equal by adjusting the ratio of pixel areas and/or the pulse widths.

#### 1. Optimise relative pixel areas

In order for the perceived brightnesses to be equal, the pixel area ratios should be the inverse of the  
10 luminance ratios or  $A(\text{blue}):A(\text{green}):A(\text{red}) = 1/100 : 1/75 : 1/10 = 0.081 : 0.108 : 0.811$ . This will lead to a perceived luminance of  $8.1 \text{ cd/m}^2$ . Lower luminance values can be achieved at optimal efficiency by changing the pulse width, although AC driving results in extra power loss. The  
15 optimal efficiency cannot be achieved for higher luminance values.

#### 1.4 Different luminance, equal voltage, different efficiency, equal life-time.

In some applications a different perceived luminance  
20 of the different pixel colours can be acceptable, e.g., in communication applications. The pixel area ratio cannot be used to equalise the half-lives at an identical pixel voltage, since with the pixel area only the perceived luminance can be modified. However, the pulse width ratio  
25 can be used to allow identical pixel voltage and identical half lives for the different pixels. An equal voltage, e.g., 4V, for all the colours and an equal life time for these colours can be achieved by changing the pulse width.



In this example, figure 8 gives the half-lives for the different colours at 4V as  $T_{1/2}(\text{red})=10000$  hrs,  $T_{1/2}(\text{green})=120$  hrs and  $T_{1/2}(\text{blue})=1000$  hrs. By choosing pulse widths inversely proportional to the half-lives, 5 identical life times are attainable, i.e.,  $\text{width}(\text{red}) : \text{width}(\text{green}) : \text{width}(\text{blue}) = 1 : 0.012 : 0.1$ . The luminance of the pixels will not be equal and are in this example:

$\text{Lum}(\text{red}) = 200 \times 1 = 200 \text{ cd/m}^2$ ;  
 10  $\text{Lum}(\text{green}) = 4000 \times 0.012 = 48 \text{ cd/m}^2$ ; and  
 $\text{Lum}(\text{blue}) = 100 \times 0.1 = 10 \text{ cd/m}^2$ .

#### 1.5 Different luminance, different voltage, optimal efficiency, equal life-time.

Another solution is to optimise the pulse width in 15 order to achieve maximal efficiency for all the colours and an equal half-life for all the colours. From Figure 9, it can be seen that operating at the optimal efficiency values (see figure 7) for red green and blue gives half-lives of 50,000 hrs, 10,000 hrs and 2,000 hrs respectively. In 20 order to obtain equal life times the pixels can be pulse-driven, leading of course to different luminances. In this example a pulse width ratio of:  $\text{width}(\text{red}) : \text{width}(\text{green}) : \text{width}(\text{blue}) = 1 : 0.2 : 0.04$  will lead to an overall half life of 50,000 hrs, however the corresponding luminance 25 values are:

$\text{Lum}(\text{red}) = 40 \text{ cd/m}^2$ ;  
 $\text{Lum}(\text{green}) = 10 \text{ cd/m}^2$ ; and  
 $\text{Lum}(\text{blue}) = 2 \text{ cd/m}^2$ .

Figure 10 shows part of a graphic display 10 incorporating a light-emitting device 12 embodying at least one aspect of the present invention. The light-emitting device 12 includes polymer-based electroluminescent elements 14, a first (14R) of which is able to emit red light when energised, a second (14B) of which is able to emit blue light when energised, and a third (14G) of which is able to emit green light when energised. The elements 14 are mounted on a transparent substrate 16 coated with transparent electrodes (not shown) as in Figure 1. The active lifetimes of and voltage drive characteristics for the three different elements are set out in Table 1.

The "red" element 14R is located centrally and the "green" and "blue" elements 14G, 14B, are located symmetrically around it. Such peripheral elements of the same colour are operated as one thus ensuring the colour centroid is at the physical centre of the device. In this example, the ratio of the areas covered by each of the elements in the device 12 is approximately one-third red to one green to three blue. (The area of the green element is first selected, and then the areas of the red and blue elements are decreased and increased respectively although not necessarily optimised according to 1.1 or 1.2.). The different coloured elements in the device may be configured to operate at a common potential, or with different potentials. Taking each scenario in turn;

#### Common Potential

At a common potential, (e.g.  $V_1$ ) the brightness of

light emitted from each element when energised will vary from colour to colour, being greatest for the red emitter and lowest for the blue emitters. This follows from Figure 3 on the assumption that the "green" emitter falls in between the extremes set by the "red" and "blue" emitters. However, the amount of light produced of the three colours will be approximately equal since total light emission is also dependent on the area from which light is emitted. Achieving even light emission for each colour is desirable in graphic displays. The "common potential" approach achieves this by increasing the area of the element(s) with the lowest brightness relative to the area of the element with the highest brightness. This is quite distinct from the use of equal areas and achieving a balance in brightness by driving the "blue" element(s) at a higher potential than the "red" element. As shown in Figure 2, the higher the brightness emitted by an organic electroluminescent element, the shorter the service life. Thus, by achieving a balance in light output using area compensation instead of voltage compensation, the "blue" element(s) may be operated at a lower brightness than the "red" element to increase service life (e.g. from  $t_1$  to  $t_2$  in Figure 2).

#### Different Potential

In view of the disparity between voltage drive characteristics of the "red", "green" and "blue" elements (see Figure 3), it may be desirable to drive the "blue" elements at a higher potential than the "red" and "green"

elements. However, driving the "blue" elements at a higher potential would increase brightness, and would seem to reduce active lifetime and hence service life, rather than increase it. Thus, it is necessary to pulse the potential to the "blue" element such that even though producing an equivalent light output to the other elements, the actual time average brightness is lowered, thereby extending active lifetime. Of course, it would be possible to drive all elements with pulsed potentials, in which case the desired effect is achieved by pulsing different elements in different ways. For example, if pulsed with the same frequency, the pulse width may be greater for "red" elements than for the "blue" elements, as shown in Figure 6. In this way, the service life of the graphic display may be increased from 1.5K hours to 4.5K hours; a three-fold improvement over the active lifetime of a blue element operated in the conventional way.

TABLE 1

20

|               | Active Lifetime      | Vol.Drive Charact. |
|---------------|----------------------|--------------------|
| Red Emitter   | 30K hours (good)     | Low                |
| Green Emitter | 10K hours (moderate) | Low                |
| Blue Emitter  | 1.5K hours (short)   | High               |

25

TABLE 2

|                                    | Equal Perceived<br>Pixel Luminance | Half<br>Life | Voltage/<br>current<br>Pixel | Efficiency        |
|------------------------------------|------------------------------------|--------------|------------------------------|-------------------|
| Equal Perceived<br>pixel Luminance | X                                  | Area<br>1.1  | Area, time<br>1.2            | Area, Time<br>1.3 |
| Half-Life                          |                                    | X            | Time<br>1.4                  | Time<br>1.5       |
| Voltage/current<br>pixel           |                                    |              | X                            | No<br>solution    |
| Efficiency                         |                                    |              |                              | X                 |

CLAIMS

1. A light-emitting device comprising: a first electroluminescent element for emitting light of a first colour when energised; and a second electroluminescent  
5 element for emitting light of a second colour when energised, the first electroluminescent element having an active lifetime which is greater than that of the second electroluminescent element; characterised in that the second element is configured to operate at a lower  
10 brightness than the first element.
2. A light-emitting device according to claim 1, in which the first or second electroluminescent elements comprise organic light emissive material.
3. A light-emitting device according to claim 2, in which  
15 the organic light emissive material is polymeric.
4. A light-emitting device according to any one of claims 1 to 3, in which the first and second electroluminescent elements are energised by a common potential.
5. A light-emitting device according to claim 4, in which  
20 the common potential is applied through an electrode common to both elements.
6. A light-emitting device according to claim 5, in which the common potential is applied between an anode and a cathode common to both elements.
- 25 7. A light-emitting device according to any one of claims 1 to 6, in which the first and second electroluminescent elements are energised by different potentials.
8. A light-emitting device according to claim 7, in which

the second electroluminescent element is energised at a higher potential than the first electroluminescent element.

9. A light-emitting device according to claim 4,5,7 or 8, in which the potential applied to one or both of the  
5 electroluminescent elements is pulsed.

10. A light-emitting device according to claim 9, in which the first electroluminescent element is energised for longer periods than the second electroluminescent element.

11. A light-emitting device according to claim 10, in  
10 which the first electroluminescent element is pulsed more frequently or with a greater pulse width than the second electroluminescent element.

12. A light-emitting device according to any one of claims 9 to 11, in which over a given period the ratio between  
15 energization times for the first and second electroluminescent elements is substantially equal to the ratio between the lifetimes of the second and first electroluminescent elements respectively.

13. A light-emitting device according to any one of the  
20 preceding claims, in which the second element is adapted to emit light over a larger area than the first element.

14. A light-emitting device according to claim 13, in which the ratio between the light-emitting areas of the first and second electroluminescent elements is  
25 substantially equal to the ratio between the brightness of the second electroluminescent element and the brightness of the first electroluminescent element when energised for equal periods.

15. A light-emitting device according to any one of claims 1 to 14, in which the first and second colours of light emission are selected from the group consisting of red, green and blue.

5 16. A light-emitting device according to any one of the preceding claims, in which the ratio between the brightness of the first electroluminescent element and the brightness of the second electroluminescent element is substantially equal to the ratio between the active lifetime of the first  
10 electroluminescent element and the active lifetime of the second electroluminescent element.

17. A light-emitting device according to any one of claims 1 to 16, further comprising a third electroluminescent element for emitting light of a third colour when  
15 energised, the third electroluminescent element having an active lifetime in between that of the first and second electroluminescent elements.

18. A light-emitting device according to claim 17, in which the third electroluminescent element is energised by  
20 the same potential as the first electroluminescent element.

19. A light-emitting device according to claim 17 or 18 when appendent to claim 13, in which the third electroluminescent element is adapted to emit light over an area which is greater than that of the first  
25 electroluminescent element but less than that of the second electroluminescent element.

20. A graphic display comprising a light emitting device according to any one of claims 1 to 19, wherein each



electroluminescent element corresponds to a pixel for displaying graphic information.

21. A light-emitting device substantially as hereinbefore described with reference to and as illustrated in the 5 accompanying drawings.

22. A light-emitting device, comprising: a first electroluminescent element for emitting light of a first brightness when energised by a predetermined potential; and a second electroluminescent element for emitting light of a 10 second brightness when energised by the predetermined potential, the second brightness being less than the first brightness; characterised by means for energising the first and second electroluminescent elements at the predetermined potential, and in that the second electroluminescent 15 element has a larger light-emitting area than the first electroluminescent element.

23. A light-emitting device according to claim 22, in which the first or second electroluminescent elements comprise an organic light emissive material.

20 24. A light-emitting device according to claim 23, in which the organic light emissive material is polymeric.

25. A light-emitting device according to any one of claims 22 to 24, in which the energising means comprises at least one electrode common to both electroluminescent elements.

25 26. A light-emitting device according to claim 25, in which the energising means comprises an anode and a cathode, each common to both electroluminescent elements.

27. A light-emitting device according to any one of claims

22 to 26, in which total light emitted by the first electroluminescent element is substantially equal to total light emitted by the second electroluminescent element in any given time interval when both electroluminescent  
5 elements are energised.

28. A light-emitting device according to any one of claims 22 to 27, in which the ratio of the first brightness to the second brightness is substantially equal to the ratio of the light-emitting area of the second electroluminescent  
10 element to the light-emitting area of the first electroluminescent element.

29. A light-emitting device according to any one of claims 22 to 28, in which the first and second electroluminescent elements emit light of first and second colours  
15 respectively when energised, the first and second colours being selected from the group consisting of red, green and blue.

30. A light-emitting device according to any one of claims 22 to 29, further comprising: a third electroluminescent  
20 element for emitting light of a third brightness when energised by the predetermined potential, the third brightness being in between that of the first and second brightnesses; and means for energising the third electroluminescent element at the predetermined potential.

25 31. A light-emitting device according to claim 30, in which the third electroluminescent element has a light-emitting area greater than that of the first element and less than that of the second element.

32. A graphic display comprising a light-emitting device according to any one of claims 22 to 31, wherein each electroluminescent element corresponds to a pixel for displaying graphic information.

5 33. A light-emitting device comprising: a first electroluminescent element for emitting light of a first colour when energized; and a second electroluminescent element for emitting light of second colour when energized, the first electroluminescent element emitting light at a  
10 lower luminance than that of the second electroluminescent element when each is energized with optimal efficiency; characterized in that the first and second electroluminescent elements are configured to operate at the same perceived brightness when both electroluminescent  
15 elements are energized with optimal efficiency.

34. A light-emitting device according to claim 33, in which the first or second electroluminescent elements comprise organic light emissive material.

35. A light-emitting device according to claim 34, in  
20 which the organic light emissive material is polymeric.

36. A light-emitting device according to any one of claims 33 to 35, in which the first and second electroluminescent elements are energized by a common potential.

37. A light-emitting device according to any one of claims  
25 33 to 35, in which the first and second electroluminescent elements are energized by different potentials.

38. A light-emitting device according to claim 37, in which the second electroluminescent element is energized at

a higher potential than the first electroluminescent element.

39. A light-emitting device according to claim 36,37 or 38, in which the potential applied to one or both of the 5 electroluminescent elements is pulsed.

40. A light-emitting device according to claim 39, in which the first electroluminescent element is energized for longer periods than the second electroluminescent element.

41. A light-emitting device according to claim 40, in 10 which the first electroluminescent element is pulsed more frequently or with a greater pulse width than the second electroluminescent element.

42. A light-emitting device according to any one of claims 33 to 41, in which the first electroluminescent element is 15 configured to emit light over a larger area than the second electroluminescent element.

43. A light-emitting device according to claim 42, in which the ratio between the light-emitting areas of the first and second electroluminescent elements is 20 substantially equal to the ratio between the luminances of the second and first electroluminescent elements respectively when energized with optimal efficiency.

44. A light-emitting device according to any one of claims 33 to 43, in which the first and second colours of light 25 emission are selected from the group consisting of red, green and blue.

45. A light-emitting device according to any one of claims 33 to 44, further comprising a third electroluminescent

element for emitting light of a third colour when energized, the third electroluminescent element emitting light at a luminance in between that of the first and second electroluminescent elements when energized with  
5 optimal efficiency.

46. A graphic display comprising a light-emitting device according to any one of claims 33 to 45, wherein each electroluminescent element corresponds to a pixel for displaying graphic information.

10 47. A light-emitting device comprising: a first electroluminescent element for emitting light of a first colour when energized; and a second electroluminescent element for emitting light of a second colour when energized, the first electroluminescent having a half-life  
15 which is greater than that of the second electroluminescent element when each is energized with optimal efficiency; characterized in that the second electroluminescent element is configured to operate at a lower brightness than the first electroluminescent element when both are energized  
20 with optimal efficiency.

48. A light-emitting device according to claim 47, in which the first or second electroluminescent elements comprise organic light emissive material.

49. A light-emitting device according to claim 48, in  
25 which the organic light emissive material is polymeric.

50. A life-emitting device according to any one of claims 47 to 49, in which the first and second electroluminescent elements are energized by a common potential.

51. A light-emitting device according to any one of claims 47 to 49, in which the first and second electroluminescent elements are energized by different potentials.

52. A light-emitting device according to claim 51, in which the second electroluminescent element is energized at a higher potential than the first electroluminescent element.

53. A light-emitting device according to claim 50, 51 or 52, in which the potential applied to one or both of the electroluminescent elements is pulsed.

54. A light-emitting device according to claim 53, in which the first electroluminescent element is energized for longer periods than the second electroluminescent element.

55. A light-emitting device according to claim 54, in which the first electroluminescent element is pulsed more frequently or with a greater pulse width than the second electroluminescent element.

56. A light-emitting device according to any one of claims 47 to 55, in which the first electroluminescent element is configured to emit light over a larger area than the second electroluminescent element.

57. A light-emitting device according to claim 56, in which the ratio between the light-emitting areas of the first and second electroluminescent elements is substantially equal to the ratio between the brightness of the second and first electroluminescent elements respectively when energized with optimal efficiency.

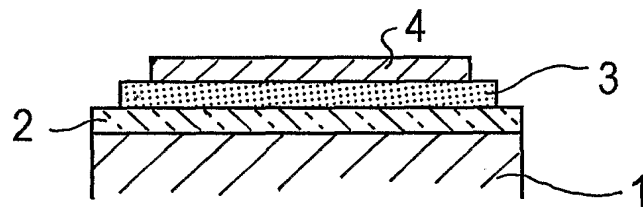
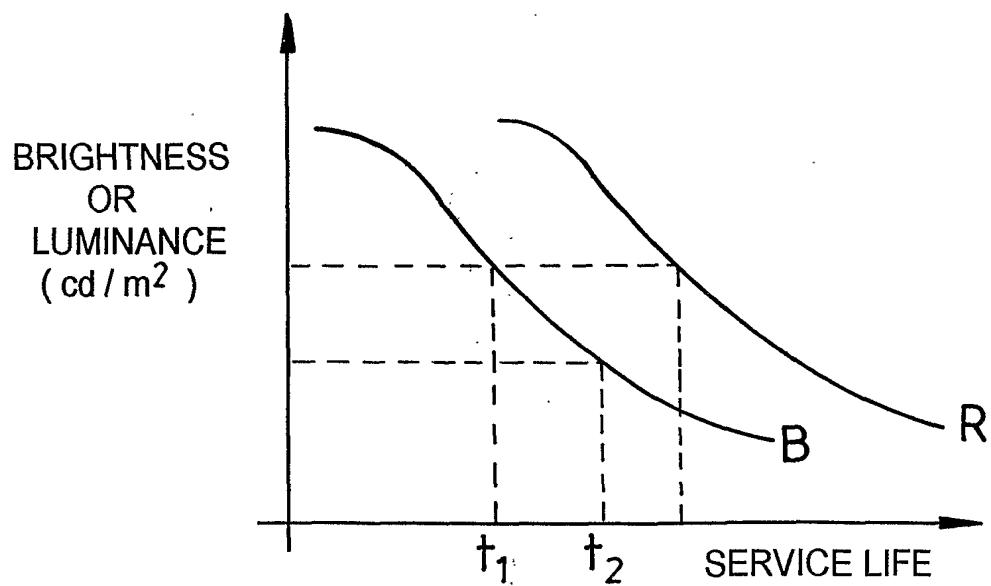
58. A light-emitting device according to any one of claims

47 to 57, in which the first and second colours of light emission are selected from the group consisting of red, green and blue.

59. A light-emitting device according to any one of claims 5 47 to 58, further comprising a third electroluminescent element for emitting light of a third colour when energized, the third electroluminescent element emitting light at a luminance in between that of the first and second electroluminescent elements when energized with 10 optimal efficiency.

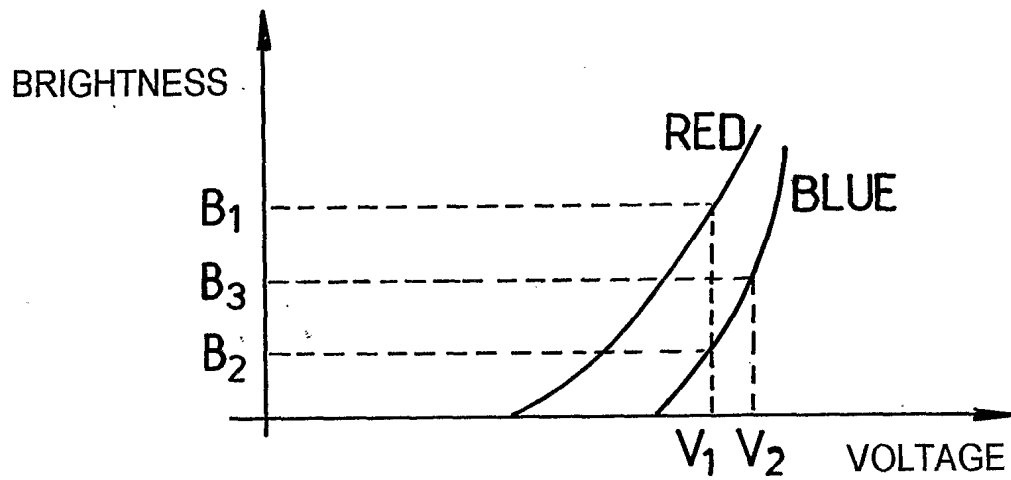
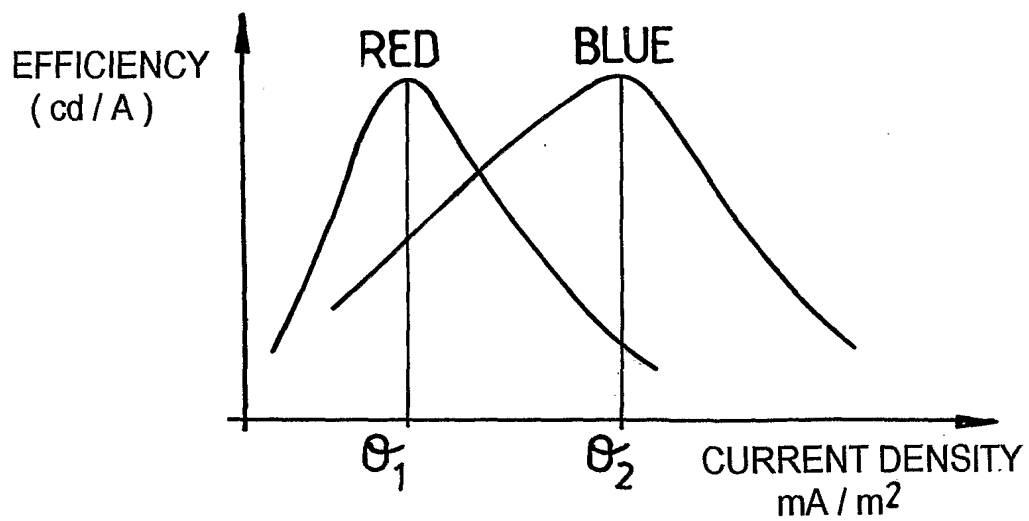
60. A graphic display comprising a light-emitting device according to any one of claims 47 to 59, wherein each electroluminescent element corresponds to a pixel for displaying graphic information.

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*Fig. 1**Fig. 2*



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*Fig. 3**Fig. 4*

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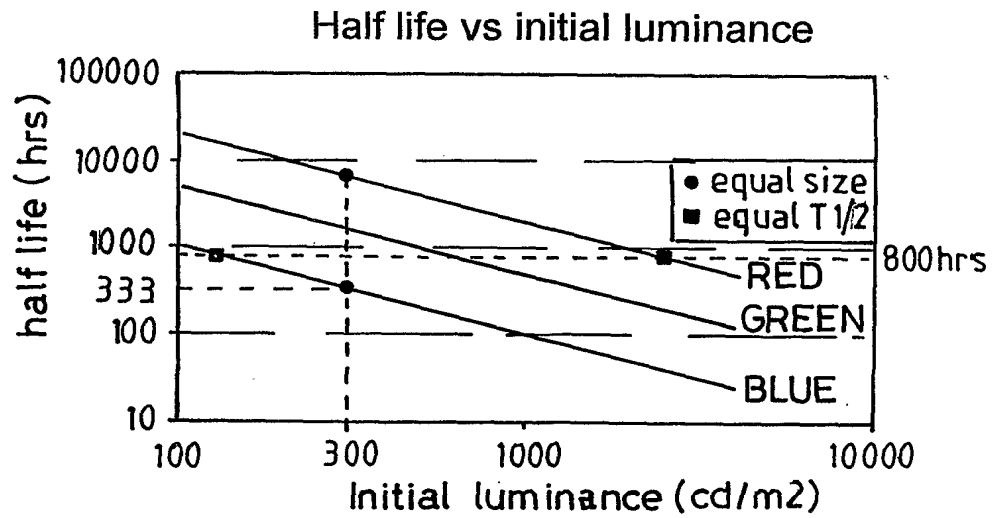


Fig. 5

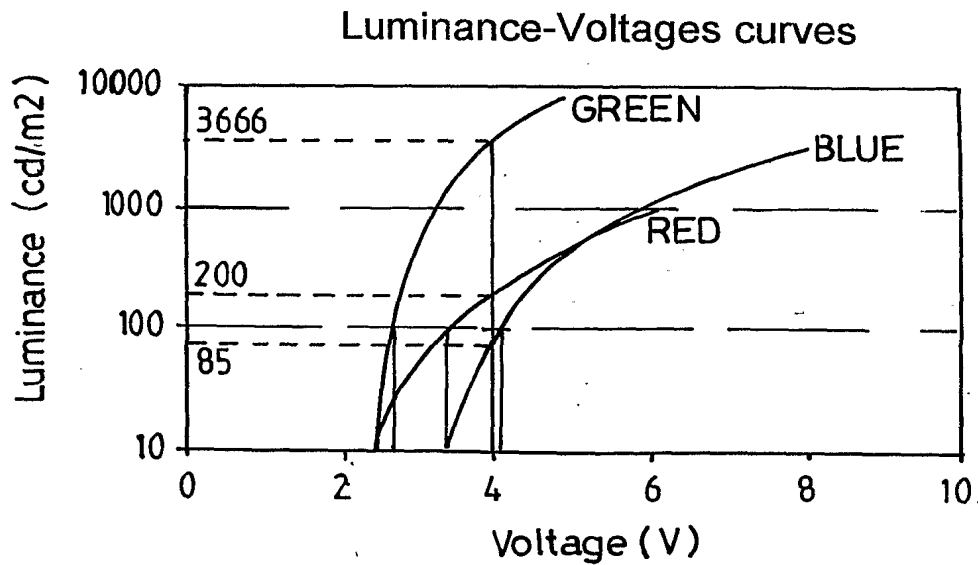
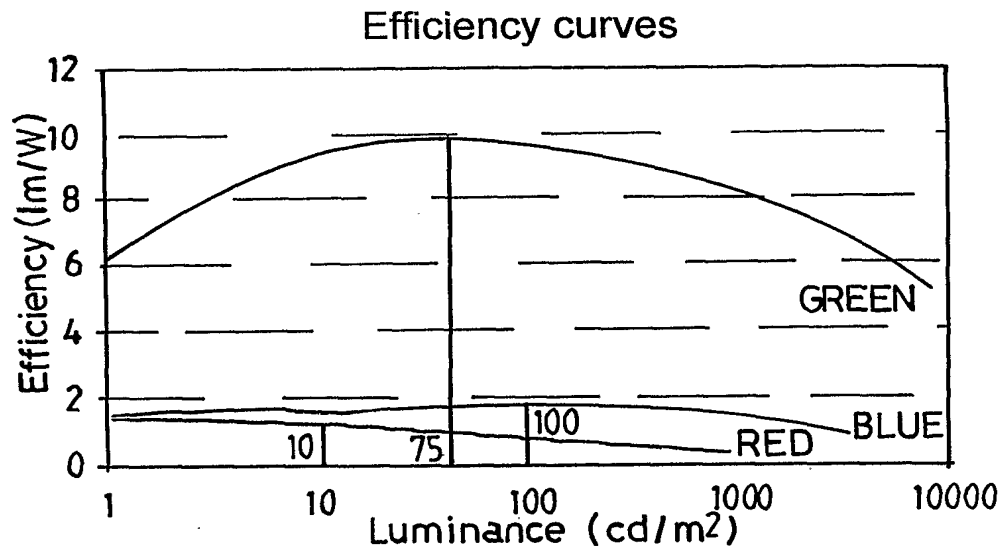
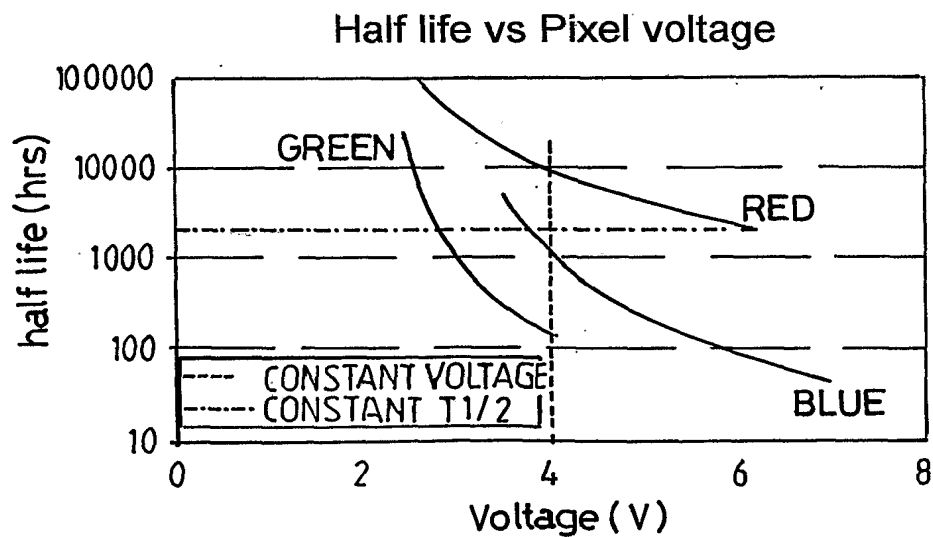
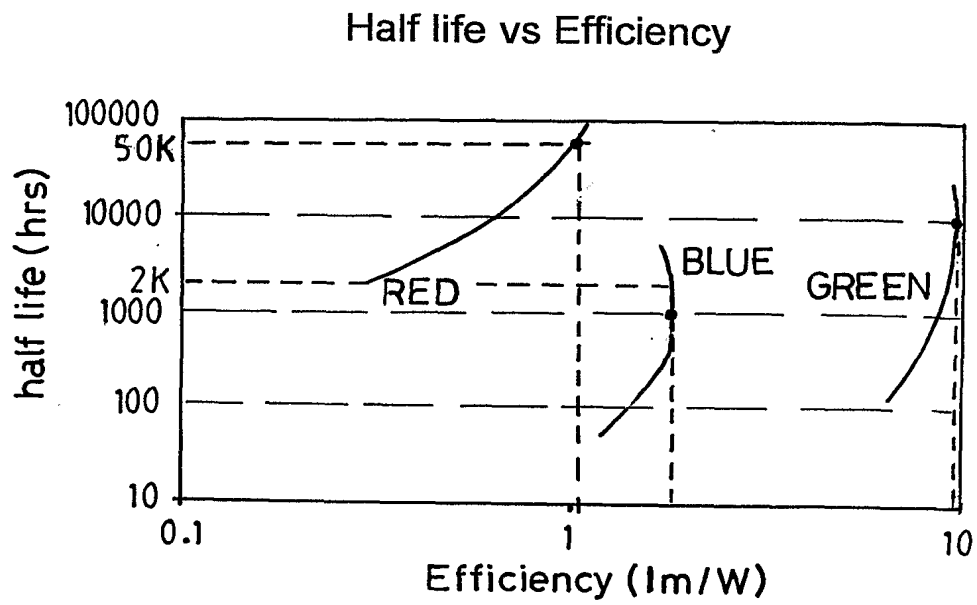


Fig. 6

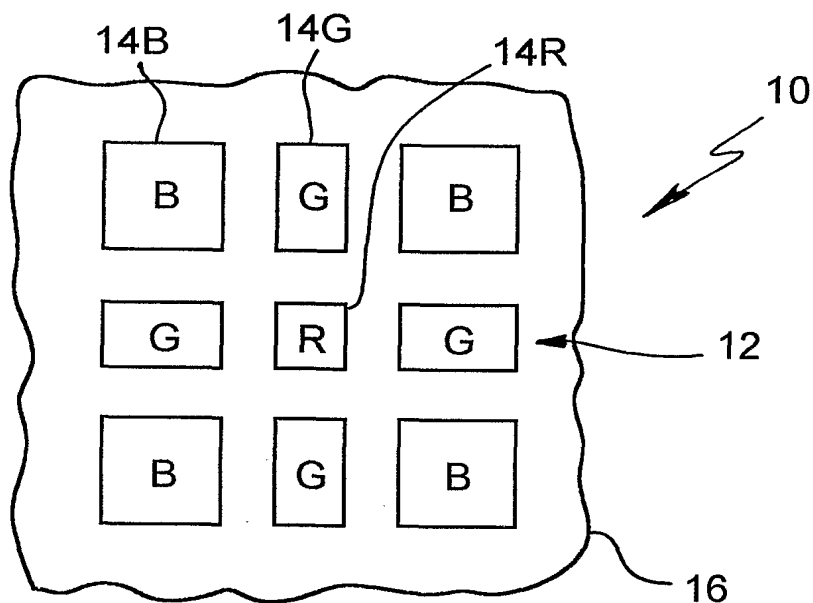
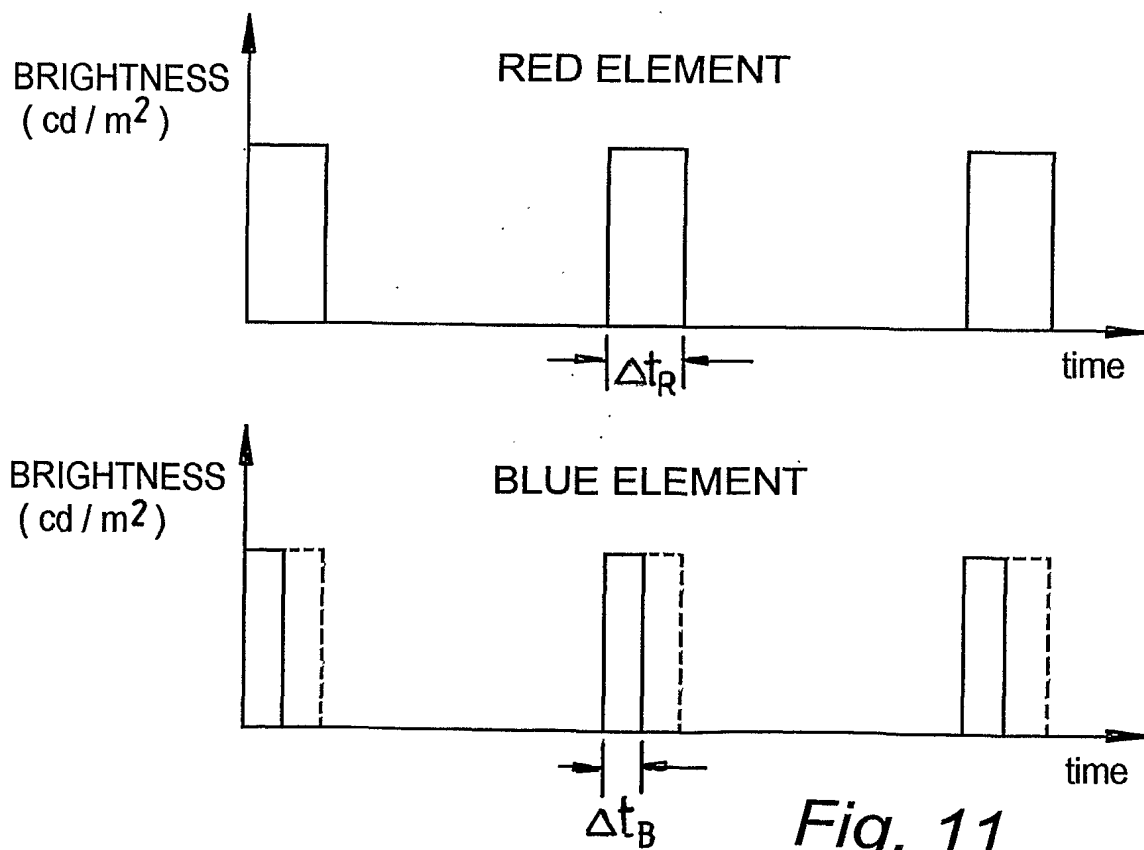
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*Fig. 7**Fig. 8*

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*Fig. 9*

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*Fig. 10**Fig. 11*

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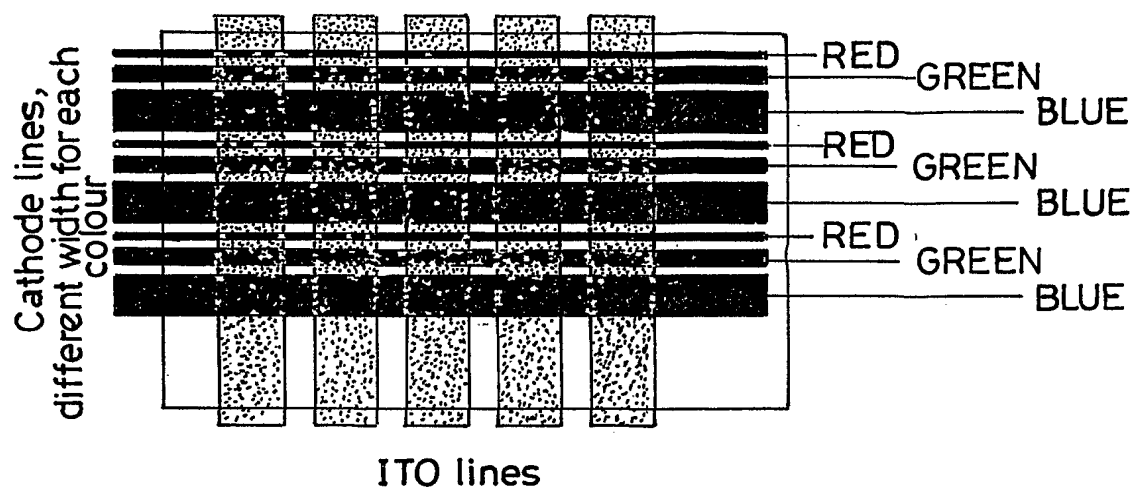


Fig. 12

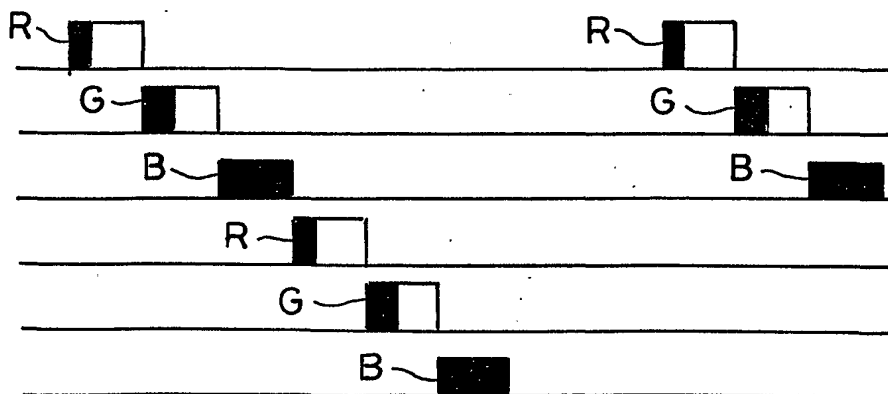


Fig. 13

## INTERNATIONAL SEARCH REPORT

Intern - Application No

PCT/GB 01/02732

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 H01L27/15

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H01L G09G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data, INSPEC

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages  | Relevant to claim No.                 |
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| A          |   | 3,6,8,<br>24,26,<br>33-60             |
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|            | ---<br>-/-  |                                       |

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☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

10 August 2001

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21/08/2001

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## INTERNATIONAL SEARCH REPORT

Internat. Application No

PCT/GB 01/02732

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages   | Relevant to claim No.  |
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Information on patent family members

Internat Application No

PCT/GB 01/02732

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